

# PROPERTIES OF ‘SUPERTHIN’ GALAXIES

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## Abstract

‘Superthins’ are a subset of edge-on spiral galaxies exhibiting disks with large axial ratios ( $a/b > 10$ ), extraordinarily small stellar scale heights, and no bulge component. These are thus examples of dynamically cold, pure disk galaxies. We have recently obtained multiwavelength (H I, optical, NIR) observations for a large sample of superthin spirals. Our data lead to a picture of superthins as ‘underevolved’ disk galaxies in both a dynamical and a star formation sense. Studies of these relatively simple disk systems can therefore provide unique constraints on galaxy disk formation and evolution without looking beyond the local universe. We present the results of a detailed analysis of the nearby superthin UGC 7321 as an illustration of these ideas.

## 1 Meet the galaxies

Vorontsov-Vel’yaminov (1967) was one of the first to draw attention to a unique subset of edge-on spiral galaxies that exhibit extraordinarily large disk axial ratios and no discernible bulge component. Goad & Roberts (1981) dubbed these galaxies ‘superthins’ and recognized that spirals selected on the basis of their superthin morphologies tend to share other unique properties, including low optical surface brightness disks, high neutral gas fractions, low metallicities, and slowly rising, dwarf-like rotation curves (see also Karachentsev & Xu 1991; Bergvall & Rönnback 1995; Matthews *et al.* 1999a).

Superthins are by no means uncommon in nearby space. From an inspection of photographic survey plates, Karachentsev *et al.* (1993) compiled a catalogue of 4454 edge-on, pure disk galaxies (the Flat Galaxy Catalogue or FGC). Our group has surveyed 474 of the FGC objects in the H I 21-cm line using the Nançay Radio Telescope and Green Bank 140-ft Telescope (Matthews & van Driel, in preparation). We detected over 50% of our targets within  $V_h < 9500 \text{ km s}^{-1}$  (see also Giovanelli *et al.* 1997). The high detection rate of our survey demonstrates that optically organized, gas-rich, pure disk galaxies are abundant in the nearby universe, and hence represent one of the most common products of galaxy disk formation. Galaxy formation paradigms must therefore explain the abundance of these small disks and their unique properties, even if their contribution to the overall matter density of the universe is small.

We have obtained follow-up optical imaging and photometry of 95 of our H I-detected galaxies using the WIYN telescope at Kitt Peak. By definition, all of the galaxies we surveyed have large disk axial ratios and little or no bulge component. However, we find the FGC galaxies are nonetheless morphologically diverse; many are true superthin objects with small stellar scale heights, while a number exhibit thicker, more flocculent disks. Interestingly, galaxies of both types may have similar disk rotational velocities, H I contents, and optical luminosities.



Figure 1: *R*-band CCD image of UGC 7321. Field size is  $\sim 5''.5$  across.

The objects exhibiting superthin morphologies are of particular interest, since the thinness of their stellar disks implies they are among the least dynamically evolved of nearby disk galaxies. Our optical images reveal that the superthins frequently appear rather diffuse, indicating the stellar densities in their disks are low. Since corresponding H I contents are generally high, this suggests that these galaxies have been inefficient star-formers. Thus superthins can be viewed as highly ‘underevolved’ systems. For this reason, superthins can offer us a glimpse of the conditions during the early stages of quiescent disk galaxy evolution without looking beyond the local universe. Moreover, these simple disks allow us to probe disk structure and dynamics without the complication of a bulge or large internal extinction. As an illustration of these ideas, we summarize the results from a detailed analysis of the nearby superthin UGC 7321.

## 2 A nearby superthin studied in detail: UGC 7321

### 2.1 Global properties

Located at a distance of  $\sim 10$  Mpc, UGC 7321 is a prototypical example of a superthin spiral (Fig. 1). Using the WIYN telescope, we obtained photometrically-calibrated *B* and *R* images of UGC 7321 under  $0''.6$  seeing conditions. In addition, we obtained complementary NIR *H*-band imaging with IRIM on the Kitt Peak 2.1-m telescope, an H I pencil-beam map using the Nançay Telescope, and we have analyzed archival VLA H I observations of this galaxy. For more details on the observations and their analysis, we refer the reader to Matthews *et al.* (1999a).

For UGC 7321 we derive the following global properties<sup>1</sup>:  $i \approx 88^\circ$ ;  $M_B = -17.0$ ;  $\bar{\mu}_B = 27.6$  mag arcsec<sup>-2</sup>;  $A_{opt} = 16.3$  kpc;  $\mathcal{M}_{HI} = 1.1 \times 10^9 \mathcal{M}_\odot$ ;  $\frac{\mathcal{M}_{HI}}{L_B} = 1.1 \mathcal{M}_\odot / \mathcal{L}_\odot$ ;  $W_{20} = 233$  km s<sup>-1</sup>;  $h_r = 2.1$  kpc. We find the rotation curve of UGC 7321 rises slowly, and begins to flatten only well outside the stellar disk. UGC 7321 can therefore be characterized as a low surface brightness, gas-rich galaxy with a rather weak central mass concentration. Its global properties are thus in some ways more reminiscent of an Irregular galaxy than an Sd spiral. Nonetheless, the stellar disk of UGC 7321 is clearly highly organized, and its double-horned global H I profile is distinctly spiralesque.

### 2.2 The radial light distribution

A fit to its azimuthally-averaged brightness distribution reveals that UGC 7321 does not have a simple exponential stellar disk (Fig. 2). At small radii a brightness excess over the best exponential fit is observed, while at large radii, the light profile falls off faster than predicted for an exponential, suggesting the stellar disk of UGC 7321 may be truncated. In addition, a major axis brightness profile extracted from our *H*-band data exhibits distinct ‘steps’ in the light distribution. These observations suggest that perhaps viscous evolution has been

<sup>1</sup>All quantities have been corrected for Galactic and internal extinction and projected to a face-on value; see Matthews *et al.* (1999a).

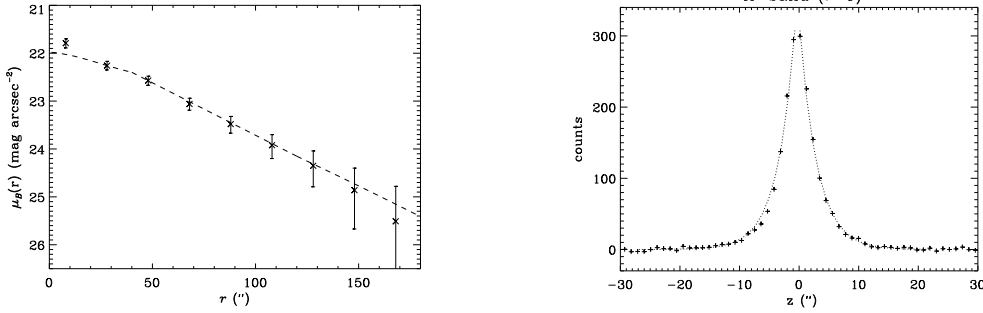


Figure 2: (Left) Azimuthally-averaged radial  $B$ -band surface brightness profile of UGC 7321 with best-fitting exponential overplotted as a dashed line. Figure 3: (Right) Vertical  $H$ -band brightness profile of UGC 7321 along the disk minor axis, with the best-fitting exponential overplotted as a dotted line.

inefficient in this low-density galaxy (see also Matthews & Gallagher 1997). This also provides evidence against the hypothesis that the exponential nature of the *stellar* disk of spirals is established by the initial conditions of galaxy formation (cf. Dalcanton *et al.* 1997).

### 2.3 Disk colors and color gradients

The examination of disk color gradients offers an important means of constraining disk formation mechanisms (e.g., de Jong 1996) and dynamical evolution histories (e.g., Just *et al.* 1996). UGC 7321 is particularly suited to the exploration of disk color gradients, since it suffers minimally from internal dust extinction (Matthews *et al.* 1999a).

Near the center of its disk, UGC 7321 exhibits a small, very red nuclear feature ( $B - R \approx 1.5$ ), only a few arcseconds across. Surrounding this feature is a more extended red region with  $B - R \sim 1.2$ , which extends to  $r \approx \pm 20''$  on either side of the disk center, and has a rather distinct boundary. Intriguingly, this region corresponds very closely to the region over which we observe a light excess over a pure exponential disk (see above). Similar regions have also been found in 3 other superthins (Matthews *et al.* 1999b); perhaps these represent ancient starbursts, the cores of the original protogalaxies, or kinematically distinct subsystems analogous to the bulges of other spirals. Cutting into the red central region of UGC 7321, we find thin blue bands of stars along the midplane of the galaxy. These bands grow both thicker and bluer with increasing galactocentric radius, having  $B - R \approx 1.05$  at  $|r| = 20''$ , and reaching  $B - R \sim 0.5$  at the visible edges of the disk. This radial bluing cannot be explained solely by dust, and is consistent with the type of color gradient predicted by ‘inside-out’ galaxy formation models (e.g., White & Frenk 1991). A faint, thicker, but highly flattened disk of unresolved stars is also visible surrounding the UGC 7321 disk at  $|r| \leq 2.0'$ . This component has  $B - R \approx 1.1$ , and shows little change in color with galactocentric distance. The color of this component is consistent with a population of ‘old disk’ stars. Their location at higher  $z$ -heights than the bluer stars along the disk midplane implies that some dynamical heating has occurred even in dynamically cold superthins.

We note that the outer disk regions of UGC 7321 are too blue to be explained by low metallicity alone and must be quite young. Nonetheless, the simultaneous presence of stars with  $B - R > 1$  implies that UGC 7321 is not a young galaxy, but rather one which has evolved very slowly. This is contrary to the picture of blue, gas-rich, low surface brightness galaxies as young systems (see also Jimenez *et al.* 1998).

## 2.4 Vertical disk structure

Measurements of the vertical light profiles of galaxy disks provide insight into their formation, stability, and evolutionary histories (e.g., de Grijs 1997 and references therein). In order to characterize the vertical light distribution of UGC 7321, we have performed functional fits to the brightness profiles extracted at various galactocentric radii from our  $H$ - and  $R$ -band images. We find the disk of UGC 7321 is not locally isothermal over most of its radial extent. At  $r=0$ , the vertical light profile can be well characterized by a single exponential function with a scale height  $h_{z,c} \approx 140$  pc (Fig 3). At intermediate galactic radii ( $0.5 \geq |r| \geq 1.5$ ), the vertical light profile becomes less peaked than an exponential and can be represented as the sum of two ‘sech’ functions of differing scale heights ( $h_{z,2} \approx 120$  pc and  $h_{z,3} \approx 218$  pc). For  $|r| \geq 1.5$  we cannot rule out that the disk may be approximately isothermal.

We interpret these results as evidence for the existence of disk subcomponents in UGC 7321, analogous to the disk subcomponents of the Milky Way (MW; e.g., Freeman 1993). At intermediate galactic radii, the two fitted sech functions may represent components similar to the “young disk” and the “thin disk” of the MW, while near the disk center, the exponential nature of the brightness profile suggests the existence of an additional component of extremely small scale height, perhaps analogous to the MW’s “nuclear disk”. This multi-disk interpretation appears consistent with the existence of various disk subpopulations delineated in our color maps (see above). Even apparently simple disks like the superthins thus appear to be quite structurally complex and to have been subject to some degree of dynamical evolution.

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